E3S Web of Conferences **438**, 01018 (2023) https://doi.org/10.1051/e3sconf/202343801018
APEE 2023

Research on the influence of boundary conditions on the simulation of the aerodynamic coefficient of power transmission towers

Xueli Zhang [1], Guo Huang [2,*], Zhipeng Li [1], Anqi Zhou [1]

[1] Beijing Electric Power Economic and Technological Research Institute, Co., Ltd, Beijing, 100055, China
[2] China Electric Power Research Institute, Co., Ltd, Beijing, 100055, China

Abstract. The shape coefficient is an important design parameter of high voltage power transmission tower. It can be obtained by means of CFD simulation. The inlet boundary condition will affect the calculation accuracy. In this paper, the turbulent inflow and the uniform inflow are used respectively. By comparing the calculation results of the two conditions, the simplified inlet condition of uniform flow is evaluated whether it is reasonable.

Key words: Power transmission tower, Shape coefficient, CFD

1. Introduction

Wind load is an important design load of high voltage power transmission tower, and the shape coefficient of towers can be obtained by CFD simulation[1-7]. The inlet boundary condition of CFD will affect the calculation accuracy. In this paper, two different types that are turbulent flow and uniform flow are set as inlet condition. The turbulent inlet condition shows the wind velocity profile and the turbulent kinetic energy and the turbulent dissipation rate, as shown in Figure 1. In the uniform inlet condition, only the wind velocity profile is given at the inlet, without considering the influence of the turbulent kinetic energy and the turbulent dissipation rate at the inlet. The turbulent inlet condition is more consistent with the actual situation, but because that the turbulence flow extends from the inlet to the outlet, which causes that the calculation time is longer than that of the uniform inlet condition. In order to assess the simplified uniform inlet condition, the calculation results of the two conditions will be compared to evaluate whether the uniform inlet condition is reasonable.

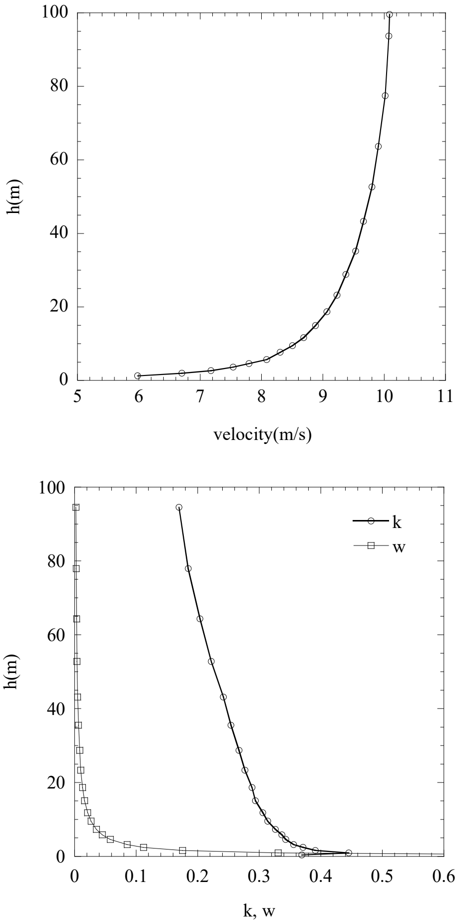

Figure 1. Wind velocity and turbulent profile

---

[*] Corresponding author: huangguocn@126.com

2. Computing model

Build the model of the steel pipe and angle steel cross arm, which consists of mixed members. The main material of the cross arm is steel pipe, and the auxiliary material is angle steel. The ventilation rate of this model is small, and the thickness of the angle steel is small. As the number of members is large, and the number of CFD grids will reach tens of millions.

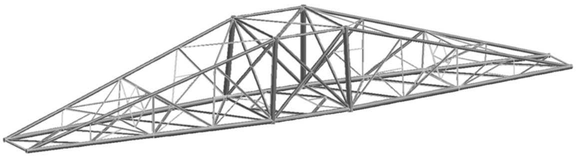

Figure 2. Steel pipe - Angle steel cross arm

Turbulence models will have a great impact on the calculation results. At present, turbulence models for engineering applications include large eddy simulation (LES) and Reynolds-average mean model (RANS). Large eddy simulation has some advantages in accurately solving the flow field, but for the calculation model with more than 10 million grids, the calculation time cost of LES is too high. However, RANS is ideal in terms of time cost performance and calculation accuracy. In this paper, standard k-e turbulence model commonly used in RANS is selected. The turbulent inlet and the uniform inlet are simulated by the internal language UDF of Fluent. The difference of the calculated results under the two conditions is evaluated and the appropriate inlet condition is recommended.

3. Boundary condition

The inflow condition of the atmospheric boundary layer is very important in computational wind engineering, and the inflow conditions contains average wind profile and turbulent flow profile. The numerical calculation is obviously affected by the inlet boundary conditions, so it is necessary to consider the appropriate inlet boundary conditions. The exponential rate model proposed by Devenport is used in the calculation to describe the average wind profile.

$$\frac{u(z)}{u_b}=\left(\frac{z}{z_b}\right)^{\alpha} \tag{1}$$

Where z_b and u_b are the standard reference altitude and the reference wind speed, respectively. z and $u(z)$ are the altitude and the average wind speed, respectively. α is the surface roughness exponent. According to the construction industry standards, the exponents corresponding to the four types of surface A, B, C and D are respectively 0.12, 0.16, 0.22 and 0.30, and the reference height z_b is respectively 5m, 10m, 15m and 30m.

The turbulent profile contains the turbulent kinetic energy and the dissipation rate. Based on the homogeneity hypothesis of turbulence, the expression of turbulent kinetic energy is as follows

$$k(z)=1.5\left[I(z)\cdot u(z)\right]^2 \tag{2}$$

For the dissipation rate, generally take the expression

$$\omega=\frac{k^{0.5}}{C_\mu^{0.25}l} \tag{3}$$

Where $C_\mu=0.09$, $l=\min(\kappa z,\kappa z_G)$, $\kappa=0.41$. In the calculation, turbulence intensity $I(z)$ is defined as

$$I(z)=\begin{cases} const & z\le z_b \\ 0.1\left(z/z_G\right)^{-\alpha-0.05} & z_b\le z\le z_G \end{cases} \tag{4}$$

Where z_G is the gradient wind height. For the four types of surface A, B, C and D, z_G equals to 300m, 350m, 400m and 450m, respectively. Other parameters are the same as the definition of the average wind profile. Type B surface is used in the calculation, and its result is compared with that of the uniform inlet to study whether the inlet boundary condition can be simplified. The uniform wind profile at inlet is shown in Figure 3.

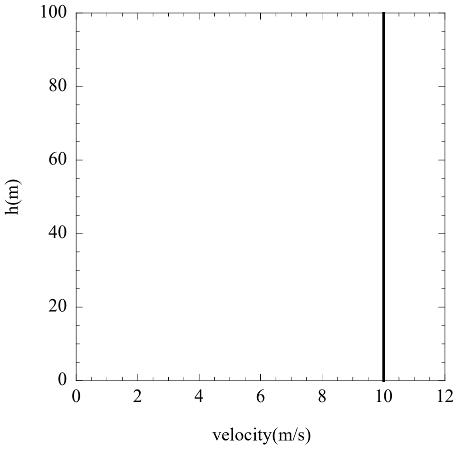

Figure 3. The uniform wind profile

4. Results

For inlet boundary conditions, one is the turbulent inlet condition, and the other is uniform one. In the uniform flow, only the uniform wind velocity profile is given at the inlet without considering the turbulent kinetic energy and the turbulent dissipation rate. From Table 1 to Table 3, it can be seen that the results of the main components of aerodynamic force are basically the same with different inlet conditions. That is to say, the aerodynamic force is not sensitive to whether the incoming flow is turbulent or not. The calculation accuracy can be satisfied by using the uniform condition, which can reduce the calculation time. Table 4 shows the coefficients of power transmission tower shape coefficients under different wind direction angles.

Table 1. The aerodynamic results

Computing domain	Wind direction	F_x	F_y	F_z	M_x	M_y	M_z
Small	0°	30.0675	-5.7408	-4.5481	0.1741	0.1166	-0.1719
Large	0°	30.1888	-5.7414	-4.5619	0.2171	0.1096	-0.1951

Table 2. The aerodynamic coefficient results

Computing domain	Wind direction	C_x	C_y	C_z	C_{mx}	C_{my}	C_{mz}
Small	0°	-0.0134	2.3472	-0.4481	-0.3550	0.0136	0.0091
Large	0°	-0.0152	2.3567	-0.4482	-0.3561	0.0170	0.0086

Table 3. The shape coefficient results

Computing domain	Wind direction	μ_x
Small	0°	2.3584
Large	0°	2.3680

Table 4. The shape coefficient results with different wind directions

Wind direction	0°	15°	30°	45°	60°	75°	90°
μ_x	2.3775	2.3181	1.6290	1.7047	1.2011	1.2340	1.1479

Acknowledgments

This work in this paper has been funded by the science and technology project of State Grid “Research on vortex-induced vibration fatigue and control technology of transmission line steel tube tower considering environmental factors”. (Project code: 5200-202156071A-0-0-00)

References

1. ZHANG Hongjie, YANG Jingbo, YANG Fengli, et al. Study on the influence of typhoon wind parameters on mechanical characteristics of transmission tower[J]. Electric Power,2016,49(2):41-47.
2. YANG Fengli, ZHANG Hongjie, YANG Jingbo, et al. Bearing capacity analysis and load values of transmission towers under thunderstorm downburst ［J］. Proceedings of the CSEE,2014,34(24): 4179-4186.
3. ZHU Kuanjun, XU Hong. Analysis on wind-induced responses of high voltage tower-line system considering the spatial-temporal distribution characteristics of wind speed[J]. Proceedings of the CSEE,2019,39(8):2348-2356.

4. LEI Xu,FU Xing,XIAO Kai, et al. Failure analysis of a transmission tower subjected to wind load using uncertainty method[J]. Proceedings of the CSEE,2018,38(S1):266-274.
5. ZHANG Hongjie, YANG Jingbo, YANG Fengli, et al. Study on the influence of typhoon wind parameters on mechanical characteristics of transmission tower[J]. Electric Power,2016,48(2):41-47.
6. LOU Wenjuan, XIA Liang, JIANG Ying, et al. Wind-induced response and wind load factor of transmission tower under terrain B wind field and typhoon wind field[J]. Journal of Vibration and Shock,2013,32(6):13-17.
7. WENG Lanxi, ZHAO Jinfei, LIN Rui, et al. Investigation of distribution characteristics of typhoon in Fujian coastal area and its influence on transmission lines[J]. Journal of Changsha University of Science & Technology (Natural Science), 2020,17(3):95-101.